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Searches for the Standard Model Higgs Boson at the Tevatron

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The CDF and DØ experiments at the Tevatron have searched for the Standard Model Higgs boson in data collected between 2001 and 2004. Upper limits have been placed on the production cross section times branching ratio to $b\bar{b}$ pairs or W^+W^- pairs as a function of the Higgs boson mass. Projections indicate that the Tevatron experiments have a chance of discovering a $M_H = 115$ GeV Higgs with the total dataset foreseen by 2009, or excluding it at 95% C.L. up to a mass of 135 GeV.

1 Introduction

The excellent agreement between experimental measurements of electroweak observables and Standard Model (SM) predictions constitute a strong motivation to search for the Higgs boson at the Tevatron [1]. The latest fits [2], which indicate as $M_H = 126^{+73}_{-48}$ GeV the most likely value for the Higgs mass, together with the direct lower limit of $M_H > 114$ GeV obtained by the LEP experiments [3], allow CDF and DØ to hope for a significant measurement before the Large Hadron Collider at CERN starts producing proton-proton collisions at a center-of-mass energy of 14 TeV.

In 2003 a joint committee of CDF and DØ members carried out a reassessment of the Tevatron reach in the search for the Higgs boson [4]. By using a more realistic model of the two detectors than the simplified one used in a study performed in 1998 [5], together with real data collected by the experiments, the committee determined that the early claims of sensitivity were not off the mark. In the meantime, the Tevatron has continued to improve its performance, recently surpassing the peak luminosity of $1.2 \times 10^{32} cm^{-2} s^{-1}$. The chances of delivering an integrated statistics of $8 fb^{-1}$ by the end of 2009 appear now sizeable. It seems therefore possible to expect that before the CMS and ATLAS collaborations start analyzing their first collisions, CDF and DØ may either discover a 115 GeV Higgs boson, or exclude it up to 135 GeV (see Fig. 1).

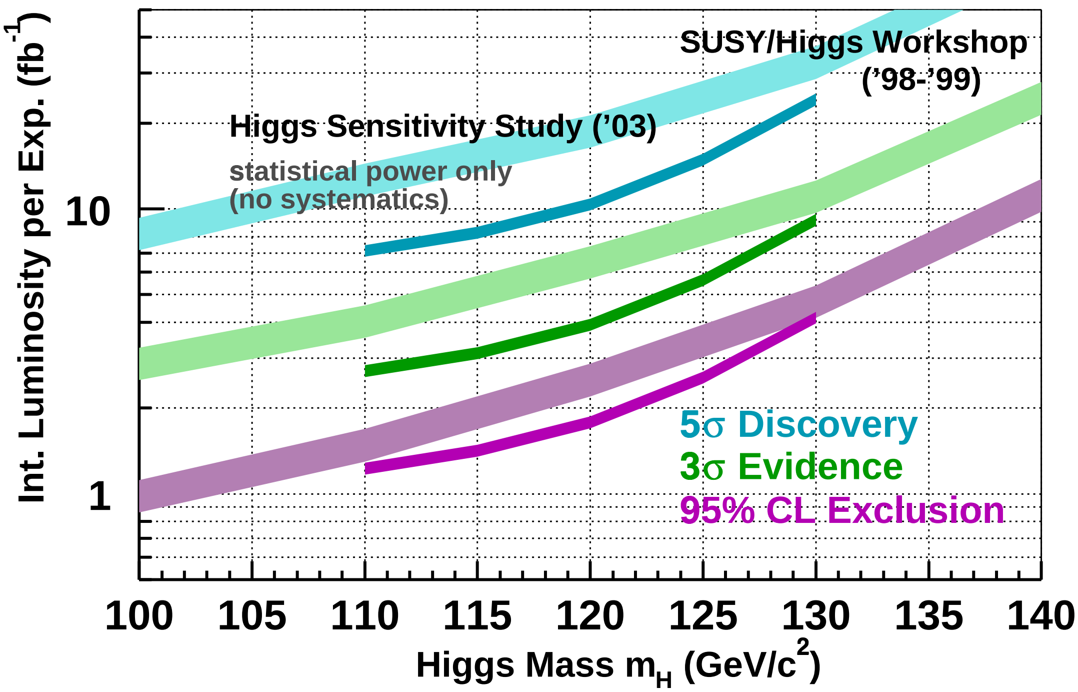

Figure 1: *The three bands show the integrated luminosity per experiment needed for a 95% exclusion (purple), a 3σ evidence (green), or a 5σ discovery (blue) of the Higgs boson as a function of the particle mass. The 2003 study, which only considers the low mass regime ($M_H < 135$ GeV), shows slightly reduced luminosity thresholds for a given mass, but does not include systematic uncertainties.*

The search for the Higgs boson at the Tevatron is carried out by looking for two different final states depending on the particle mass. For masses below 135 GeV, the dominant decay is $H \to b\bar{b}$, and the search channels always include an accompanying W or Z boson signature; the latest results from CDF and DØ in these final states are given in Sec. 3. For masses above that threshold, the $H \to W^+W^-$ decay is the most promising one, and both direct production and production in association with an additional electroweak boson are considered; results are discussed in Sec. 4.

2 Tools

The smallness of the Higgs boson signal at the Tevatron, when compared with competing backgrounds, implies that for a successful search many tools have to be crafted to the highest standards: a performant lepton identification, efficient b-quark tagging, and precise jet energy measurement.

Both CDF [6] and DØ [7] excel in detecting high-P_T electrons and muons generated from W or Z boson decay. Their signal constitutes the trigger for all datasets used in the analyses described in this paper.

When searching for light Higgs boson decays, the identification and precise measurement of b-quark-originated jets is crucial. To successfully tag b-jets both detectors are endowed with dedicated silicon detectors which can measure the impact parameter of charged tracks with a resolution of few tens of microns, thereby allowing to determine the decay point of B hadrons. Other methods rely on an estimate of the global probability that all tracks in a jet come from the primary interaction vertex, or on the identification of electrons or muons from the semileptonic decay of B particles. A lot of work has gone into perfecting these algorithms, and both collaborations claim a 45% to 50% efficiency to identify secondary vertices in central b-jets, with

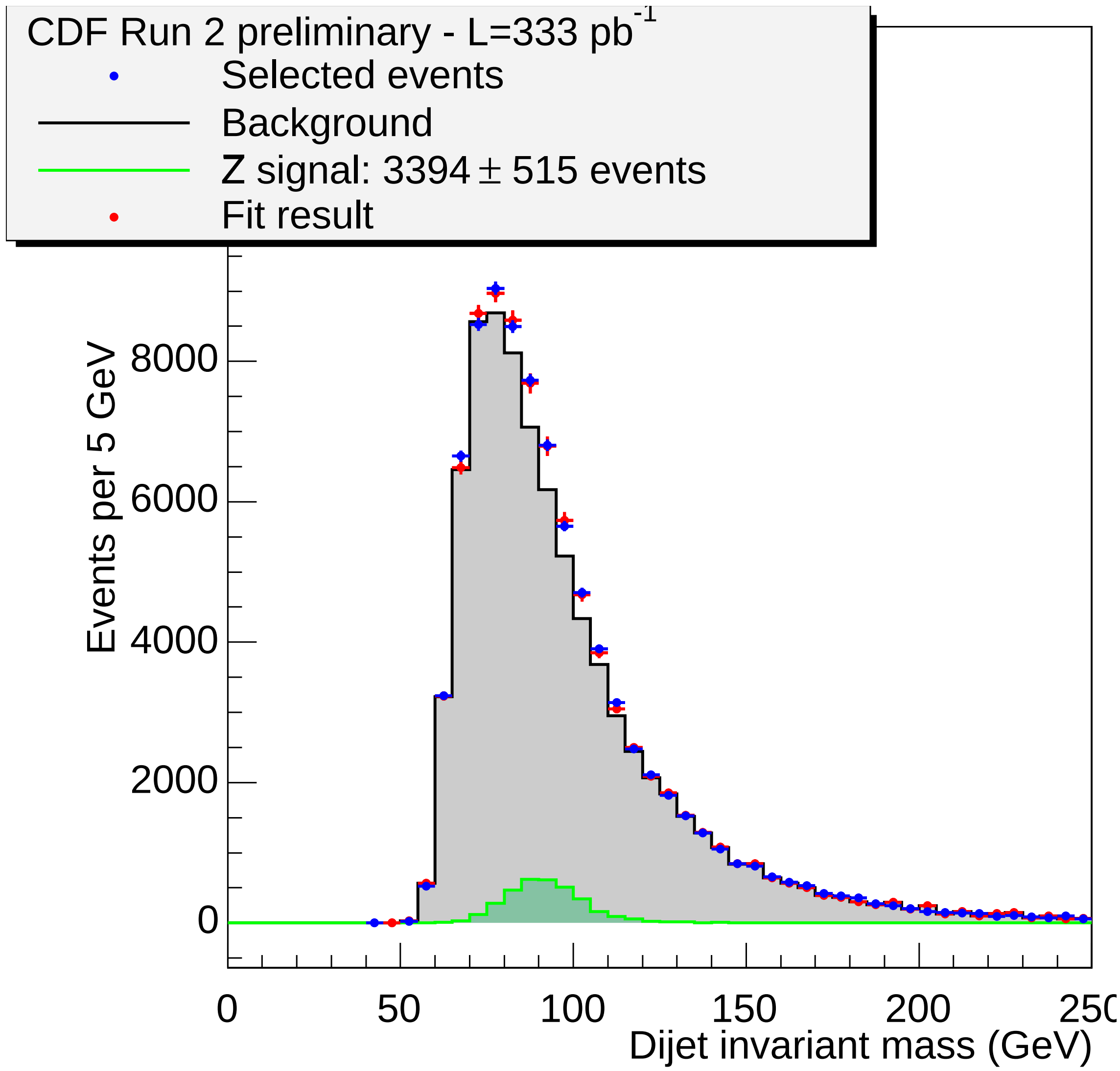

Figure 2: The signal of $Z \to b\bar{b}$ decays extracted from 333 pb^{-1} of CDF Run 2 data is visible as an excess of events in the dijet mass region around 90 GeV. The green histogram shows the fitted Z contribution.

fake rates of less than a percent.

The goal for the precise measurement of the energy of b-jets is set by the Higgs Sensitivity Working Group. They claimed that by using advanced algorithms a relative resolution $\sigma_{M_{jj}}/M_{jj} \sim 10\%$ was attainable on the dijet invariant mass pair of b-quark jets from $H \to b\bar{b}$ decay [4]. This is still to be demonstrated on the data. The most stringent tests foresee using the Z boson decay to $b\bar{b}$ pairs, both to check the absence of systematics in the determination of the b-jet energy scale and to verify the dijet mass resolution.

CDF has recently identified a first signal of $Z \to b\bar{b}$ decays from a dedicated dataset, thanks to a online trigger designed to select low-E_T jets containing charged tracks with large impact parameter identified by the silicon vertex tracker [8]. Fig. 2 shows the Z signal, whose size and shape are in good agreement with expectations. Besides providing a precise measurement of the b-jet energy scale, the data will be used in studies aimed at improving the dijet mass resolution, to increase the chances of a Higgs discovery in the $b\bar{b}$ final state.

3 Light Higgs Boson Searches

Both CDF and DØ have analyzed their Run 2 datasets in search for associated production of a W boson and a pair of b-quark jets from $H \to b\bar{b}$ decay, using the dijet mass distribution to extract limits to the cross section times branching ratio of the process.

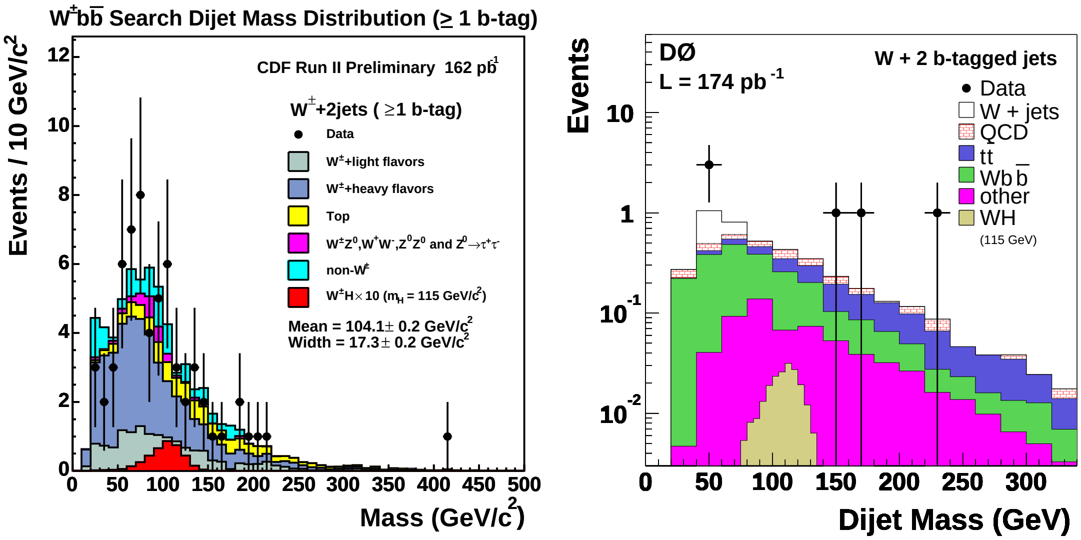

Figure 3: *The dijet mass distribution of 62 b-tagged W +2 jet candidates (black points) is understood as a sum of several contributing SM backgrounds (left); a* $H \to b\bar{b}$ *signal 10 times larger than expected is overlaid. Right: the dijet mass of double b-tagged W+ 2 jet candidates found by DØ ; the expected* $H \to b\bar{b}$ *signal is overlaid.*

In $162pb^{-1}$ of collider data CDF finds 62 events with a clean $W \to l\nu$ ($l = e, \mu$) candidate and two jets, one of which tagged by secondary vertex identification; estimated SM backgrounds amount to 66.5 ± 9.0 events (Fig. 3, left). From a fit of the dijet mass distribution of these events a 95% C.L. limit of about $5pb$ is obtained, with little dependence on the Higgs boson mass (see Fig. 5).

DØ similarly finds 76 events in $174pb^{-1}$ of $p\bar{p}$ collisions yielding a $W \to e\nu$ signal and two jets, at least one of which with a b-tag. Estimated backgrounds amount to 72.6 ± 20.0 events. The subset of 6 events with both jets b-tagged is then divided in search windows in the dijet mass distribution, to extract cross section limits to Higgs boson production (Fig. 3, right). The result is a 95% C.L. limit of $\sigma_{WH} \times B(H \to b\bar{b}) < 9$ to $12pb$ for $M_H = 115$ to 135 GeV (see Fig. 5).

4 High Mass Searches

For $M_H > 135$ GeV the $H \to WW^{(*)}$ decay mode becomes dominant. When both W bosons decay to an electron-neutrino or muon-neutrino pair the final state is very clean, with residual backgrounds mostly due to Drell-Yan production of lepton pairs. To discriminate direct production of a Higgs boson from non-resonant WW production it is useful to study the azimuthal angle $\Delta\Phi_{ll}$ between the two charged leptons, since the zero spin of the Higgs boson and helicity conservation conspire to produce leptons in the same direction in the transverse plane.

CDF selects W pairs by searching for lepton pairs of opposite charge, $P_T > 20$ GeV, and then applying a missing E_T cut at 25 GeV and a tight jet veto. A small dilepton mass is then required ($M_{ll} < 55$ (80) GeV for $M_H = 140$ (180) GeV). After this selection, 8 events are observed in $184pb^{-1}$ of data, where 8.9 ± 1.0 are expected from non-Higgs SM sources. A likelihood fit to

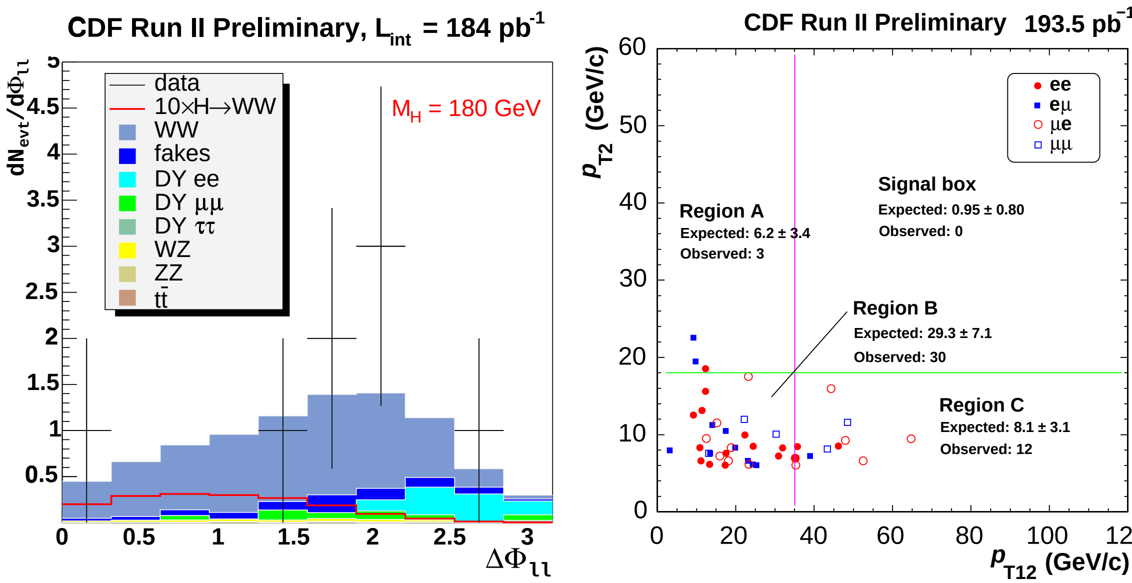

Figure 4: *Azimuthal angle between charged leptons in the CDF $H \to WW$ analysis (left). Distribution of the vector sum of lepton transverse momenta (P_{T12}) versus subleading lepton transverse momentum (P_{T2}) for same-sign dilepton candidates found by CDF (right).*

the $\Delta\Phi_{ll}$ distribution is performed to extract a 95% C.L. limit on the cross section as a function of M_H (see Fig. 4, left). The result is $\sigma_H \times B(H \to WW) < 5.6pb$ for $M_H = 160$ GeV. DØ similarly searches for WW pairs in $177pb^{-1}$ of Run 2 data. They require the azimuthal angle between the charged leptons to be smaller than 2.0 radians, and find 9 WW candidates, when 11.2±3.2 are expected from non-Higgs SM sources. They thus obtain $\sigma_H \times B(H \to WW) < 5.7pb$ at 95% C.L. for $M_H = 160$ GeV.

CDF also searches $193.5pb^{-1}$ of data for the striking signature of associated WH production at high M_H, when the event may yield *three* W bosons. The search starts from a dataset of lepton pairs of same charge, which is understood as a sum of fake lepton backgrounds and SM sources (see Fig. 4, right). Optimized cuts are then applied to the leptons transverse momentum and to the vector sum of lepton transverse momenta, $P_{t_{12}} > 35$ GeV. Zero events are observed, with 1.0 ± 0.6 expected from known sources. A 95% C.L. cross section times branching ratio limit of $8pb$ can thus be set for $M_H = 160$ GeV (see Fig. 5).

5 Conclusions

The Higgs boson is being hunted at the Tevatron in all advantageous search channels. If the actual luminosity delivered by the accelerator keeps following expectations, the Tevatron experiments have a real chance of observing a $M_H = 115$ GeV Higgs boson before the end of 2009, or exclude its existence if $M_H < 135$ GeV.

Acknowledgments

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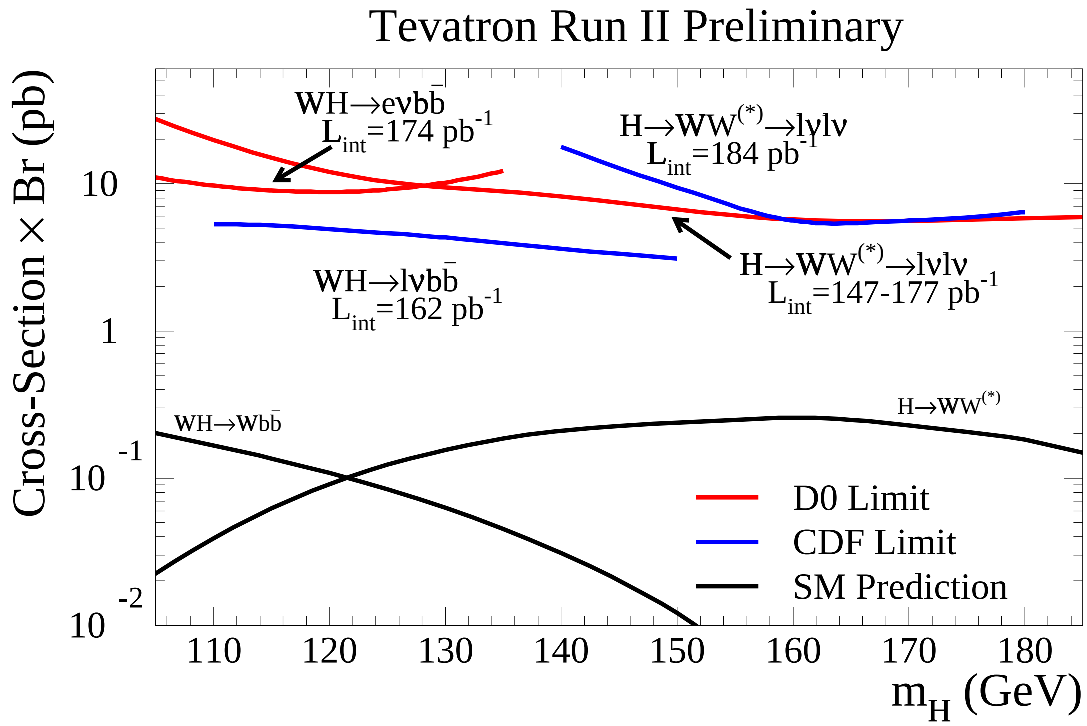

Figure 5: *Summary of 95% C.L. limits obtained by CDF and DØ from Run 2 searches of the Higgs boson. The expected SM cross section for the searched processes is in black.*

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